N73 29807

NASA TECHNICAL MEMORANDUM

NASA TM X-68280

NASA TM X-68280

INFLUENCE OF NOISE REQUIREMENTS ON STOL PROPULSION SYSTEM DESIGNS

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TECHNICAL PAPER proposed for presentation at
the 42nd Meeting of the Propulsion and Energetics Panel
of the Advisory Group for Aerospace Research and Development,
North Atlantic Treaty Organization
Schliersee, Germany, September 17-21, 1973

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E-7601

SUMMARY

The severity of proposed noise goals for STOL systems has resulted in a new design approach for aircraft propulsion systems. It has become necessary to consider the influence of the noise goal on the design of engine components, engine systems, and the integrated nacelle, separately and collectively, from the onset of the design effort. This integrated system design approach is required in order to effect an optimization of the propulsion and aircraft system.

Results from extensive design studies and pertinent test programs are presented which show the effect of noise specifications on component and system design, and the trade-offs possible of noise versus configuration and performance. The design optimization process of propulsion systems for powered lift systems is presented beginning with the component level and proceeding through to the final integrated propulsion system. Designs are presented which are capable of meeting future STOL noise regulations and the performance, installation and economic penalties are assessed as a function of noise level.

INTRODUCTION

In recent years considerable development activity has been expended exploring various powered lift concepts for Short-Haul Aircraft systems. Two of the most promising concepts, which utilize the externally blown flap (EBF) over-the-wing (OTW) and under-the-wing (UTW) high lift systems, will, in the near future, be evaluated in the Air Force's Advanced Military STOL Transport (AMST) program. A third propulsive lift concept, the Augmentor Wing (AW) is currently being tested in a joint United States/Canadian program using a modified C-8A aircraft. The aircraft for all of the above programs are not fitted with propulsion systems which would be acceptable for commercial use. This is primarily because of the noise restraints that are envisioned for commercial short-haul systems.

Aside from field length, the noise requirement has probably the most bearing on the design of the propulsion system for short-haul aircraft. The effect of the generally discussed 152 M (500 ft.) sideline noise goal of 95 EPNdB for STOL aircraft has been evaluated through comprehensive design studies and component development activity. Some of the results of this effort are presented in this paper. The effects of the noise goal are examined on the design of the turbomachinery, engine cycle, and nacelle acoustic design. The overall performance of propulsion systems capable of meeting the noise goal is described, and the economic penalties resulting from the noise requirement are assessed.

ACOUSTIC DESIGN TRADE-OFFS

The Noise Problem

The design execution of a STOL aircraft which is capable of meeting the STOL noise goals presents a most formidable challenge. A feel for the magnitude of the required low noise level can be obtained by comparing the noise footprint area of a current aircraft (fig. 1) which meets the FAR 36 regulation, with the footprint area that would be produced by a STOL aircraft capable of meeting a 610 M (2000 ft.) field length and a 95 EPNdB sideline noise level. The achievement of such a decrease in noise area requires a significant departure from present propulsion system design practice which normally attempts to reach an optimization between system performance and economic return to the user. With a very low noise goal, it is found that the design effort must initially concern itself with satisfying the noise requirement and then effecting an optimization between aerodynamic and economic performance.

In addition to having to suppress the conventional engine noise sources, e.g. machinery and jet noise, the designer of STOL propulsion systems must also consider an additional noise source which is that due to the generation of powered lift. For the externally blown flap lift system, this is the noise that is generated by the impingement, or flow, of the exhaust streams along the wing surfaces and against and through the flap system. For the augmentor wing configuration, the additional noise is due to the discharge of the high pressure air stream through the augmentor nozzles.

Figure 2 shows the effect of exhaust velocity on scale models of the UTW configuration. Note the pronounced effect of flap position on noise as compared to that produced by the nozzle alone. Also note that the slope of the EBF noise curves are less, and that larger nozzle exhaust velocity reductions are required for a given noise level decrease when the wing and flap system are present. The scale model test results shown have largely been substantiated by full scale wing and engine tests (ref. 1). Acoustic evaluations of the OTW (ref. 2) and augmentor wing (ref. 3) powered

lift systems have shown that the noise generated by these lift systems is a significant a problem as it is with the UTW systems.

The reduction of powered lift noise sources requires a new design approach which also considers the tradeoffs possible between the aerodynamic performance of the lift system and the noise generated. Unfortunately, the trades appear to be limited. Let us now examine some of the design trades that are possible in the overall design of propulsion systems for STOL aircraft.

Jet Noise

Above a velocity of approximately 305 m/sec (1000 ft/sec) it has generally been accepted that jet noise total sound power varies as the eighth power of velocity. Below 305 m/sec (1000 ft/sec), test results from actual engines have shown a deviation from this correlation. It is felt that the deviation from the V^8 parameter found with actual turbofan and turbojet engines is due to so-called "core noise." Recent scale model and full scale fan tests (ref. 4) have yielded jet noise data which shows that good correlation is obtained with the V^8 parameter below 305 m/sec (1000 ft/sec). In the discussion that follows jet exhaust noise will be defined as that which follows the V^8 relationship, excludes core noise, and is generated by interaction of the airstream outside of the fan and core exit nozzles.

The exhaust jet noise for both the EBF and AW powered lift systems must be reduced to a value which when added to the machinery noise and powered lift noise will result in the desired noise goal. A balanced acoustic design would probably require jet noise to be below 90 EPNdB. Excluding the jet caused power lift noise, the amount that the total exhaust velocity (core and fan) should be reduced to achieve this low noise is shown graphically in figure 3. Note the low values of velocity required for STOL systems as compared to those which are typical of current CTOL systems. These low core velocities are representative of high energy extraction engines which are typical of turboshaft type designs. But for STOL systems, this energy must be absorbed by the fan. As with the core, the jet velocity of the fan has to be kept at a low value to keep jet noise low. Figure 4 shows the resulting fan exhaust velocities that are obtained with a low valued constant core exhaust velocity. The resultant fan design which satisfies both the low core and fan velocity requirement is a very high by-pass low pressure ratio design. As shown in the figure, equal low exit velocities of 213 m/sec (700 ft/sec) from the core and fan nozzles require a fan which has a pressure ratio of approximately 1.30.

In selecting a fan stage pressure which will yield a desired nozzle velocity, it should be kept in mind that significant losses can result from the exhaust configuration, in particular, if acoustic suppression is used in the flow path. Similarly, in establishing a design value for the core exit velocity, the effects of airbleed and power extraction should be considered inasmuch as they will effect the core exit velocity when in use.

Techniques such as multitube nozzles, have been used in the past to suppress jet noise. These nozzles shift the frequency spectrum to higher values thus taking advantage of the suppression obtained through atmospheric attenuation. Unfortunately, this technique appears to offer noise reduction only with exhaust velocities greater than around 305 m/sec (1000 ft/sec), which are above those that appear desirable for core velocities for the EBF and AW engines and for fan exhaust velocities for the EBF systems. The multinozzle approach is used, however, very effectively in the discharge of the AW system where the nozzle pressure ratios are high (2.5-3.0) (ref. 3). Another form of mixer, which combines the fan and core flow with ambient air, has been evaluated (as will be discussed later) for EBF powered lift noise reduction. As velocity decayers these devices perform their function but with an attendant increase in jet noise which results from the more intense mixing process.

The exhaust jet noise for the UTW and OTW propulsion system is also dependent on the nozzle configuration which is used, and whether the core and fan flows are mixed or separate. High bypass fan engines with variable pitch fans, which have reverse thrust capability, are well suited for using coannular separate flow nacelles. The OTW technique for lift generation requires an exhaust configuration which facilitates exhaust flow attachment to the wing. This requirement lends itself to exhaust nozzles of noncircular shape. Both the aerodynamic and acoustic performance of the nozzle configuration must be determined in assessing its relationship to the design of the overall system.

From the above discussion, it is seen that, in establishing the design value for jet noise, the primary variable that will be used is velocity.

Fan Noise

One element of engine turbomachinery that has been subjected to substantial acoustic analysis, design and test in recent years is the fan. This is because fan noise is a most dominant, difficult and costly noise source to reduce.

The augmentor wing powered lift system requires a fan stage of relatively high pressure ratio (2.50-3.0) while the EBF powered lift system fan stage requirements are at the very low pressure ratio range of 1.25-1.35. Certain principles of acoustic design of fans are applicable to both powered lift systems. Examples of these are: reduction of noise by the elimination of inlet guide vanes; sufficient rotor-stator spacing to allow rotor wakes to decay before impinging upon the stators; and the use of the Tyler-Sofrin theory (ref. 5) to provide optimization of stator vane to rotor blade number to insure that blade passage frequency tones do not propagate to the far field. Though these design principles are common to high and low pressure ratio fans, it is only of recent times that high pressure ratio fans have been built to evaluate these principles, e.g. large chord spacing in multistage fans. Other techniques such as leaned stators, which have shown a few dB advantage in single stage fans are yet to be evaluated in multistage fans.

Testing has shown that fan tip speed is a most important parameter in reducing fan noise. Fans with subsonic tip speeds have noise spectra that is characterized by the discrete tones of the blade passage frequency and its harmonics plus broadband noise. Fans with tip speeds that are supersonic have the same spectra as subsonic fans plus a large number of multiple pure tones that are associated with the irregular leading edge shock patterns which occur at multiples of the rotational speed of the fan.

The fans that are best suited for the EBF systems are subsonic. This is due to the fact that if the powered lift noise is to be reduced, relatively low fan exhaust velocities and low pressure ratio fans are required. A number of large scale fans (1.83 m dia.) have been built and evaluated for their acoustic signature. Results from the testing of subsonic fans in the pressure range of 1.15 to 1.5 have shown that for each doubling of tip speed the fan noise increases by 15 PNdB, thus showing the decided advantage for maintaining low tip speeds (ref. 6).

Figure 5 presents a current summary of the acoustic performance of single stage low speed, high speed, and two stage fans. The area of interest for EBF propulsion systems is the curve showing the performance of low speed single stage fans. Of special interest are the two points at fan pressure ratios approximating 1.20. These two fans were designed for EBF UTW applications. The data point labeled "variable" is for a fan that has variable pitch capability, a tip solidity of 0.913, 15 rotor and 11 stator blades. The data point labeled "fixed" is obtained for a more conventional fan design. This fan has a tip solidity of 1.188, 42 rotor blades and 50 stator blades. Both fans were evaluated in 1.83-m (6-ft.) diameter size. A key feature of both fans is that they were acoustically designed to provide a blade passage frequency below 2000 Hz. Blade passage frequency of the variable pitch fan was approximately 650 Hz and of the fixed pitch fan, 1700 Hz. Tip speed of the variable and fixed pitch fans were 213 m/sec (700 ft/sec) and 229 m/sec (750 ft/sec) respectively. These two fans were designed for low noise, and as can be seen from the figure, have demonstrated extremely low noise levels.

Noise levels that might be expected of fans generating the high pressure ratios of 2.5 to 3.0, characteristic of augmentor wing propulsion systems, are shown on the two-stage fan curve of figure 5. As mentioned previously, data for two-stage fans has been obtained from relatively old fans that were not designed with acoustic goals in mind. It has been theorized that if designed with acoustic specifications as a goal, the noise levels of these fans might be comparable to the results obtained from high speed single stage fans. Regardless of which curve is used, it is seen that a substantial, approximately 20 PNdB, difference in noise level exists between fans for EBF and AW systems.

Although significant reduction in fan noise can be achieved by proper acoustic design practice, much more suppression must be provided for higher pressure ratio fans if STOL noise goals are to be realized. This additional reduction can be obtained with acoustic suppressors. Two types of suppressors, passive and active, have been explored in detail in the past few years for reduction of inlet noise. Passive suppression utilizes dissipative acoustic liners. The active uses the sonic inlet principle and requires mechanization to vary the flow area as a function of engine power. Significant amounts of suppression can be obtained with either system but with attendant performance and economic penalties. Recent testing with a quieted TF-34 engine, which has a bypass ratio of 6:1, and a fan pressure ratio of 1.5, yielded data pertinent to the design of very highly suppressed fans using passive suppression. With the design configuration shown, figure 6, fan pure tones were reduced as much as 50 dB in the far field (fig. 7) at rated speed. The overall engine noise suppression measured was 23 PNdB. The suppressed inlet total pressure loss was 1.5 percent.

Tests (ref. 7) conducted with 30.5-cm (12-in.) scale model fans, and sonic inlets of various configurations, have shown that the sonic inlet is also extremely effective in reducing all pure tones and that 28 to 30 PNdB inlet noise reduction can be achieved with a 0.97 total pressure recovery. Full scale demonstrations of a practicable sonic inlet have yet to be demonstrated.

Referring back to figure 5, it is seen that quieting a fan for an EBF propulsion system to the STOL noise goals requires significantly less suppression than for the AW propulsion system. The AW system will more than likely require an inlet suppressor of the sonic inlet type, while the low pressure ratio fans for the EBF systems will require acoustic treatment and splitters. An alternate design technique for inlet suppression which uses a partial sonic inlet, with flow Mach numbers in the range of 0.65-0.80, can provide additional design flexibility. This is because of a 2-6 dB reduction which can be obtained at these Mach numbers which may obviate the need for inlet splitters for low speed and low pressure ratio fans. The partial sonic inlet may also be used with splitters to provide the high level of attenuation required for multistage fans.

Core Noise

Test data obtained from a number of turbofan engines indicates that if machinery noise and jet noise can be suppressed to low levels, noise referred to as core noise may provide the noise floor limit. Although the exact mechanisms of core noise are not well understood, its constituents appear to be turbine noise, combustor noise and aerodynamic noise caused by flow impingement on turbine exit struts, etc. Aside from the high frequency turbine noise, core noise is normally thought of as being low frequency noise (less than 500 Hz).

A number of tests have been conducted to evaluate and separate out the various constituents of core noise (ref. 8-10). These tests have shown the following:

a) Wide spacing of turbine blade rows which is used effectively in fan designs, provides significant turbine noise reductions but at the expense of weight increase and performance loss.

b) Combustion noise is largely low frequency and that substantial noise is generated when the burner pres-

sure drop is high. The combustor noise is as may be expected a function of the combustion chamber design. Small burners with resistance produce more noise.

c) Core noise can be reduced with the use of core suppressors. Test results showing the suppression that was achieved with low and high frequency core suppression on a TF-34 engine are shown in figure 8. It can be seen that the overall noise is reduced more at the low speeds than it is at the higher speeds. This is because once the fan noise was suppressed, the jet noise dominated the spectra. A measurement of core suppression was obtained by the use of a directional microphone array which focused on the core exhaust plane. Data indicated that about 9 dB of suppression was obtained at an approach thrust power setting.

Various core noise prediction procedures have been developed which are based on emperical data (ref. 11). The low frequency constituent has been found to correlate with compressor discharge pressure and with temperature rise and pressure drop across the combustor. Spectral shape of the combustion noise is taken to be broadband, with a general peak in the vicinity of 200-400 Hz. The turbine noise is calculated separately and includes both interaction tone noise and broadband noise. Turbine noise and low frequency noise are combined spectrally to yield core noise estimates.

Good design criteria and design techniques are lacking for the reduction of core noise. Some reduction can be obtained with design trade-offs which consider turbine rotor-stator spacing, combustion chamber design, improved aerodynamic flow passages and struts, and acoustic suppression.

Powered Lift Noise

Externally blown flap powered lift noise has been investigated in some detail both in small and large scale model cold gas tests and with actual engines and representative wing and flap systems (refs. 1, 2, and 12). Results from these tests have shown that the most important engine parameter controlling powered lift noise is the velocity of the exhaust flow. The tests have also shown that the OTW lift system provides substantial shielding of the aft end noise. Figure 9 compares the noise level patterns obtained from large scale model tests (ref. 13) for both the UTW and OTW powered lift systems.

Low powered lift noise requires low exhaust velocities and thus low fan pressure ratios. It is also possible to provide low flap impingement velocities by using special exhaust nozzles which break up the fan streams into smaller jets, thus producing more rapid mixing and a large velocity decay over a shorter distance. This method of reducing impingement noise results in mechanical complexity, lower cruise performance and an increase in system weight. An example of a velocity decayer that was used with an engine is shown in figure 10. This particular configuration was designed to provide ejector type augmentation at takeoff speeds to offset the thrust lost during the mixing process. The ejector also includes acoustic suppression to reduce mixing noise. Approximately 50 percent reduction (6-7 PNdB) in powered lift noise was obtained with this mixer.

Empirical curves have been developed for predicting UTW and OTW powered lift noise. These curves are based on large amounts of scale model and limited amounts of full scale engine and wing tests (refs. 2 and 12). Under the wing noise has been found to correlate very well with fan and core exhaust velocities and jet discharge areas for a given flap angle. Over the wing noise has also been shown to correlate well with exhaust velocity and flap position.

As mentioned previously, powered lift noise for the augmentor wing system results from the discharge of a high pressure air stream through a slot type discharge nozzle. The result is a noisy, supersonic jet discharge which, however, is reducible by acoustic design techniques. Greater than 20 PNdB of suppression has been achieved (ref. 3) by breaking up the slot nozzle to increase the frequency, baffling air gaps, and acoustically treating the ejector flap system.

PROPULSION SYSTEM DESIGN

The incorporation of the acoustic design philosophies and factors discussed previously into optimized powered lift propulsion systems has been done to date only in design studies. Results from one of these studies ("Quiet, Clean STOL Experimental Engine Study Program") which describes the acoustic design process, is presented below for the EBF powered lift system.

Certain basic acoustic principles were incorporated in the design of all the configurations studied. These were:

a) The use of single stage fans without inlet guide vanes and with an axial spacing between rotor and stator of two tip chords.

b) Rotor blade number to stator vane number set at a ratio of two.

c) The use of mixed flow or two position nozzles to reduce takeoff noise.

d) High inlet throat Mach numbers (0.70-0.80).

The noise goal for the study was 95 EPNdB at 152-m (500 ft.) sideline. Each source noise was targeted below the goal to insure that the summation of the system sources would not exceed the desired total. A range of engine

cycles with fan pressure ratios from 1.15 to 1.40 were explored.

Figure 11 depicts inlet radiated fan noise as a function of fan stage pressure ratio at takeoff. Also plotted are representative values for fan tip speeds. It can be seen that above a pressure ratio of 1.30 the use of higher tip speed fans reflects in substantially greater unsuppressed fan noise. Note also the suppression that is attributable to the use of high Mach number flow in the inlet. For the various fan pressures the amount of acoustic suppression required to meet the component suppressed values is also shown. Of significance is the fact that it is only at the very low, 1.25 and below fan pressure ratios, that it is possible to eliminate the use of inlet splitters.

For the same series of fans, figure 12 shows the degree of suppression required for the fan aft noise with an engine under-the-wing installation. Acoustic splitters are required over the entire range of fan pressure ratios along with extensive wall treatment. The acoustic shielding which is obtained with the OTW installation is shown in figure 13.

Powered lift noise for both the UTW and OTW installations is shown in figure 14. For both systems, it can be seen that this noise source controls the design fan pressure ratio to the values in the range of around 1.20 to 1.26 for this particular study. Velocity decayers can be used above pressure ratios of 1.25 to lower the powered lift noise with some penalty in system performance. Once again the acoustic advantage of the OTW installation is seen. The noise generation process for the OTW system is quieter than for the UTW. At higher flap settings, such as approach, the difference in flyover noise level between the OTW and UTW system increases to approximately 7-9 PNdB in favor of the OTW system.

The effect of variations in cycle parameters such as turbine inlet temperature, and overall pressure ratio were also examined as a function of system noise. The baseline turbine inlet temperature was 1589° K and the overall pressure ratio 20:1. Variations in temperature from 1489° K to 1920° K and pressure ratio from 15:1 to 25:1 were reflected as changes in bypass ratio since a constant core exit velocity was maintained. The overall system noise tradeoff was found to be less than 1 PNdB.

An evaluation was made of the trade between fan tip speed (noise) against thrust and weight for an engine design with a nominal 1.35 fan pressure ratio. Figure 15 shows the reduction in fan duct pressure loss, and thrust savings versus fan tip speed. A reduction in fan tip speed from 286 to 244 /ms (940 to 800 ft/sec) was found to reduce the fan noise approximately 3 PNdB which in turn resulted in an acoustic treatment saving of 22 Kg (48 lb M). At a tip speed of 244 m/sec, the reduction in total duct pressure loss, (inlet and exhaust), also provided a thrust saving in cruise of approximately 0.356 K N (80 lb f) which is about 4 percent of the total cruise thrust loss. Further reductions in tip speed continue the favorable trend but are more difficult to achieve in terms of fan design.

Design configurations for both EBF lift systems which are felt to be capable of meeting a system 95 EPNdB sideline noise are shown in figures 16 and 17. Included also is a list of the pertinent cycle parameters for each propulsion system.

ECONOMIC FACTORS

The noise goal has been shown to have major effects on the design configurations of the various powered lift propulsion systems. Let us now examine how the noise goal influences the economic performance of the aircraft system. Figure 18 provides a comparison of both the UTW and OTW system using a 1.35 PR UTW engine which is designed to provide a 100 PNdB sideline noise as a base for comparison. It is seen that at the very low noise goal the variable pitch fan provides a decided economic advantage over the fixed pitch fan UTW engine system. Low pressure ratio (high bypass) fans are very large and heavy. The advantage of using composite fan blades is also shown for the high bypass system.

The large advantage in D.O.C. shown in figure 18 for the variable pitch fans is largely due to the tradeoff obtained between thrust reversing with variable pitch fans versus conventional target or cascade reversers with fixed pitch fans. The weight of conventional thrust reversers for engines with fans below a pressure ratio of 1.30 significantly exceeds the weight of the gearing, pitch change mechanism and variable area nozzle required for variable pitch fans.

Referring to the plot for the OTW system in figure 18, it is seen that a titanium bladed fan at 1.30 PR can be used for the same D.O.C. value as for the 1.25 PR variable pitch fan in the UTW engine. However, for a fixed pitch fan, the OTW system has a direct operating cost 13 percent less than the UTW system for the same noise goal. The noise shielding that is characteristic of the OTW installation permits higher pressure ratio propulsion systems to be utilized than for the UTW system. The higher takeoff fan pressure ratios result in more available cruise thrust. In addition, the fan and jet noise shielding reduces the amount of aft end suppression required which results in less thrust installation loss than with a UTW system of the same fan pressure ratio.

It is also seen from figure 18 that significant economic returns can be obtained with small relaxations in noise goal. A two EPNdB relaxation in the noise goal yields a 7-8 percent decrease in D.O.C. for the fixed pitch installations.

Results from a different trade of the overall acoustic design are shown in figures 19 and 20. These figures show the variation in D.O.C. and sideline noise as a function of fan pressure ratio for the UTW and OTW powered lift systems. The comparison is made using the 1.25 FPR variable pitch engine as a base configuration. Two acoustic designs were used for the study. One is referred to as "maximum" suppression and includes acoustic wall treatment,

and except for the variable pitch fan, has one splitter in the inlet and one to two splitters in the fan exhaust duct. The configuration referred to as "wall only" suppression has no splitters in its design. It can be seen that for an approximate 4-5 PNdB noise increase in the UTW system, a 4-5 percent decrease in D.O.C. is realized by removing the splitters. In addition, design and maintenance simplicity is achieved. Similar benefits are shown for the OTW system but with greater economic returns. Removing the acoustic splitters yields a 4-6 percent D.O.C. decrease with a tradeoff of only 1-1/2 to 2 PNdB. The figures also indicate the magnitude of the noise-D.O.C. trade with fan pressure ratio.

CONCLUSIONS

A STOL sideline noise goal of 95 EPNdB has been shown to severely influence the design of propulsion systems for powered lift aircraft. Each noise source, e.g. fan, jet, core and powered lift, must be examined individually and collectively to provide optimized acoustic and aerodynamic system performance.

Externally blown flap powered lift noise which is a resulting effect of the lift generation process was shown to have the greatest influence on the basic engine cycle. The most powerful engine variable for its control is exhaust velocity. Reductions in velocity to the level required to meet the noise goal results in fan designs of very low pressure ratios, (1.25-1.35). The acoustic shielding obtained with the OTW system permits a higher pressure ratio fan to be used than with the UTW system.

Fan noise can be reduced to the very low values required through the use of acoustic treatment, sonic inlets or a combination thereof. Single stage fans with low tip speeds are good candidates for low noise systems. Core jet velocity for both the EBF and AW lift systems should be kept low in the range of 214-244 m/sec (700-800 ft/sec) in order to eliminate jet noise as a controlling factor.

Once jet and fan machinery noise is suppressed, the low noise goal requires that consideration be given to other internal noise sources commonly referred to as core noise. Lack of good test data, and analyses, makes the core noise area currently the most uncertain with respect to design control.

Propulsion system designs for both the EFB and AW powered lift aircraft have been effected which can meet the STOL aircraft sideline noise goal. The economic penalties for achieving this goal are severe. A 5 PNdB relaxation of the goal was shown to result in large economic returns and to significantly simplify the acoustic design. The advantage of a variable pitch fan engine over a fixed pitch engine for the UTW lift system has also been shown.

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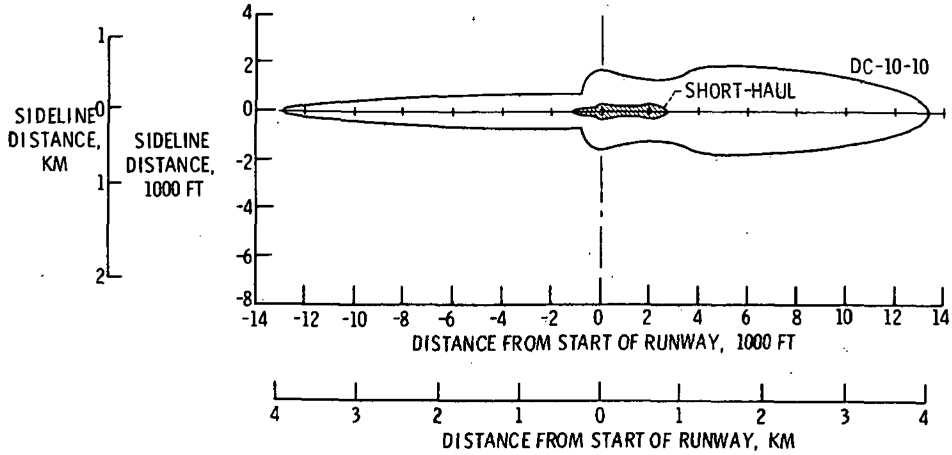

Figure 1. - Estimated 100 PNdB noise footprints for a DC-10-10 and for short-haul airplane capable of 95 PNdB on 152 m (500 ft) sideline. Mission 927 km (500 nautical miles).

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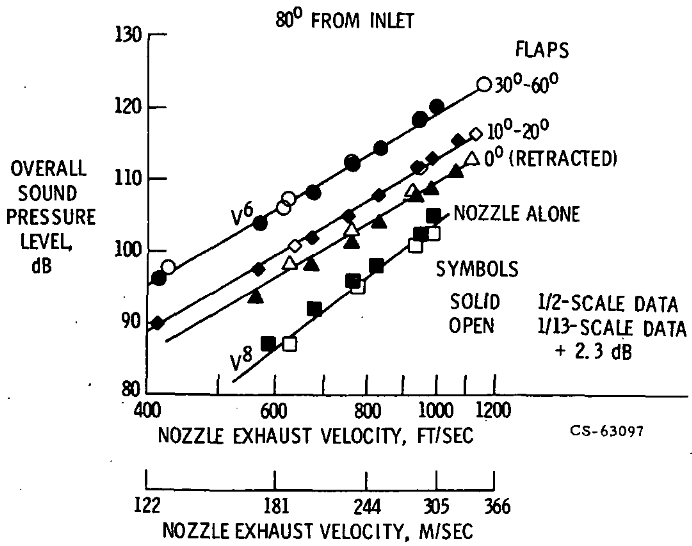

Figure 2. - Effect of velocity on flap noise level at 50 ft.

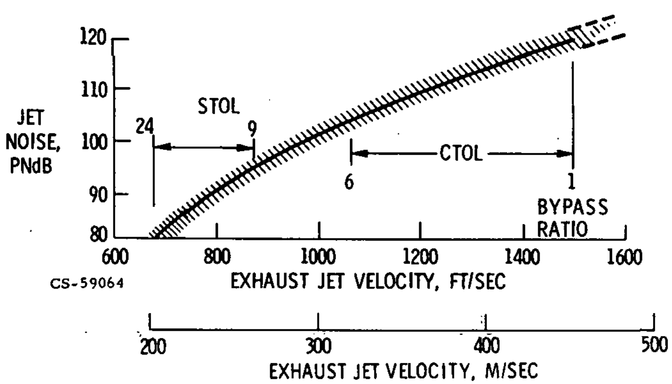

Figure 3. - Exhaust jet noise. 153 m (500 ft) flyover, total thrust 430 KN (97 000 lb) (4-engines).

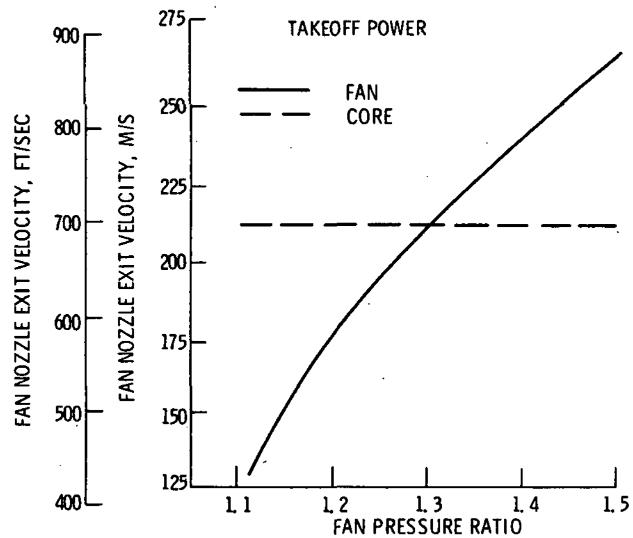

Figure 4. - Fan nozzle exit velocity.

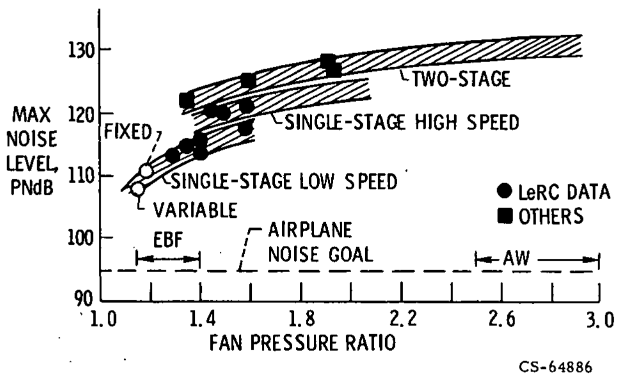

Figure 5. - Unsuppressed fan noise four engines 400 K N (90 000 LB) takeoff thrust, 152 M (500 FT) sideline.

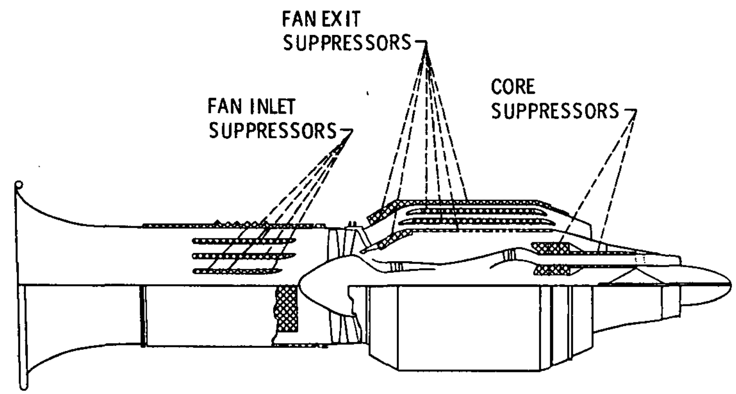

Figure 6. - TF34 engine with fan and core acoustic treatment.

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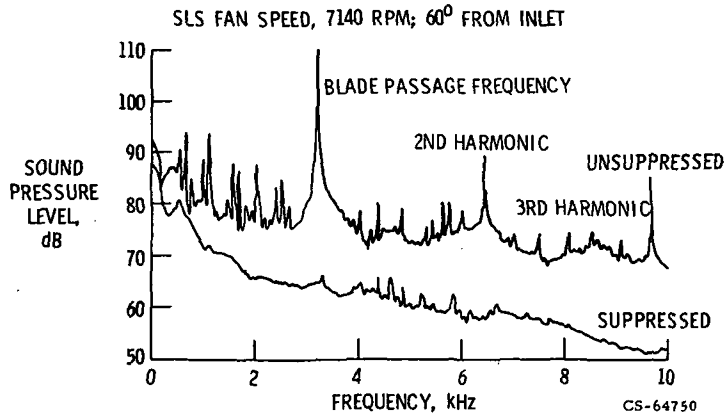


Figure 7. - TF-34 noise spectra at 30.5 m (100 ft).

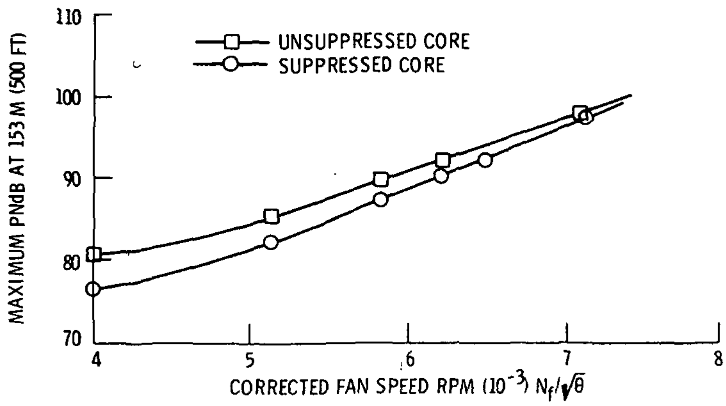


Figure 8. - Effects of acoustic core suppression on a quieted TF 34 engine.

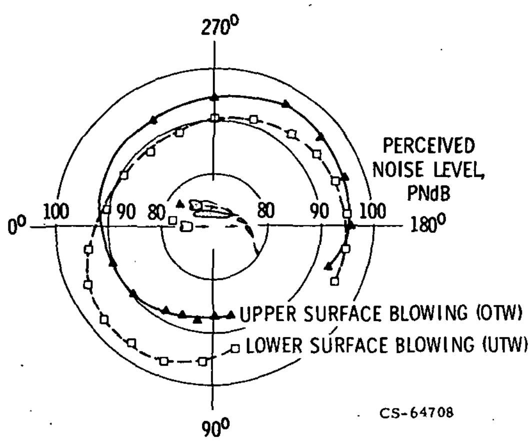


Figure 9. - Comparison of EBF perceived noise level patterns at 153 m (500 ft). Nozzle diameter, 33 cm (13 in.). Wing chord length, 7 ft. Flap position, 30° - 60°. Exhaust velocity, 153 m (207 m/s).

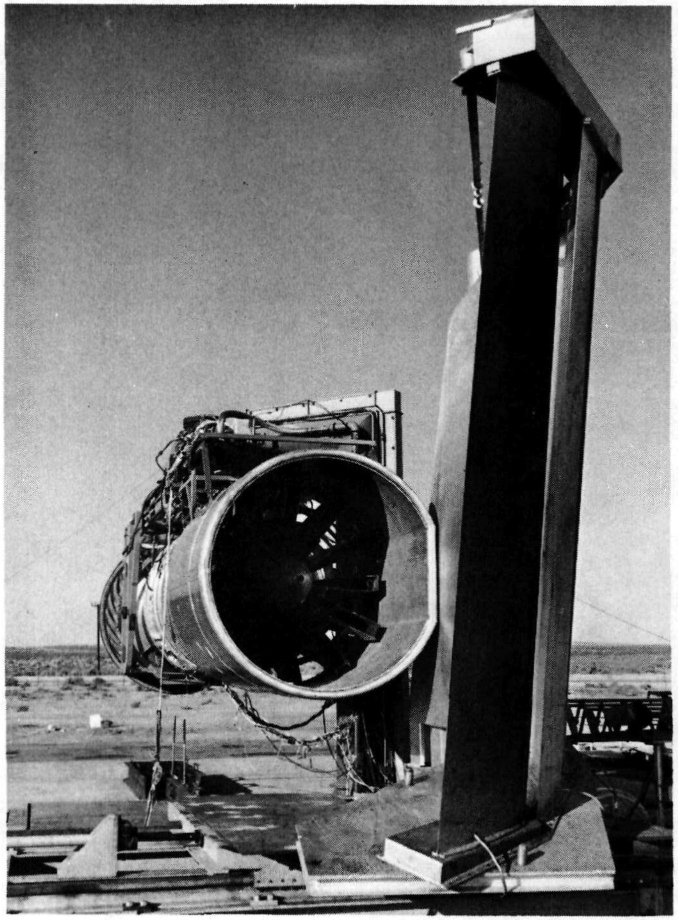


Figure 10. - TF34 engine with exhaust velocity decayer and acoustically treated ejector shroud.

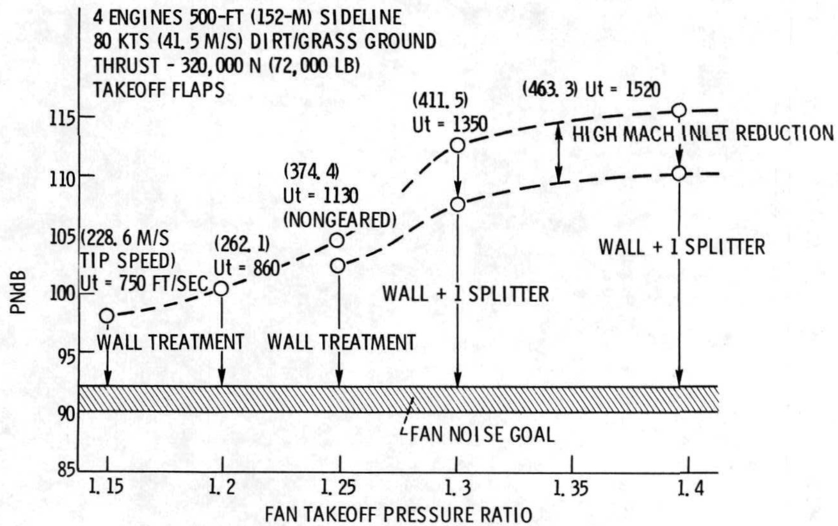


Figure 11. - Inlet radiated fan noise, EBF system.

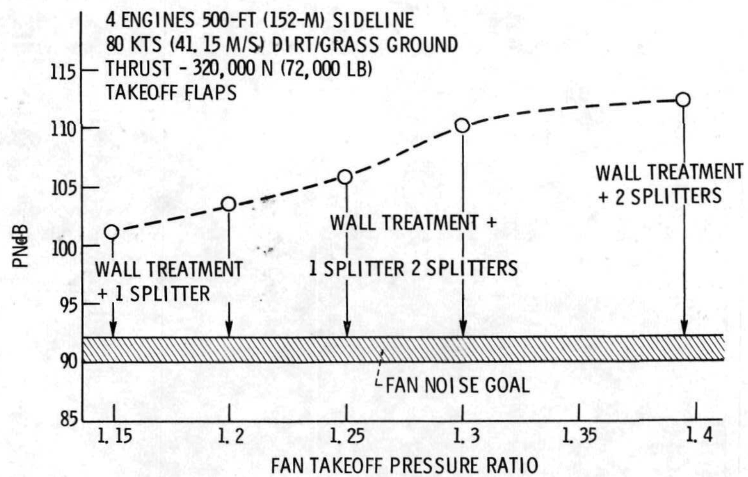


Figure 12. - Aft fan noise, under-the-wing installation.

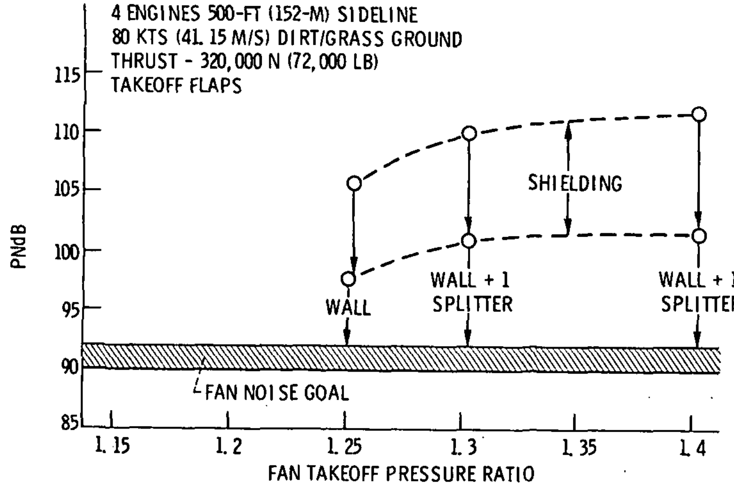


Figure 13. - Aft fan noise, over-the-wing installation.

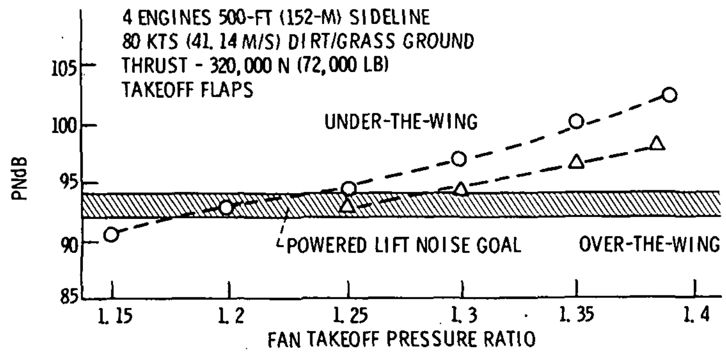
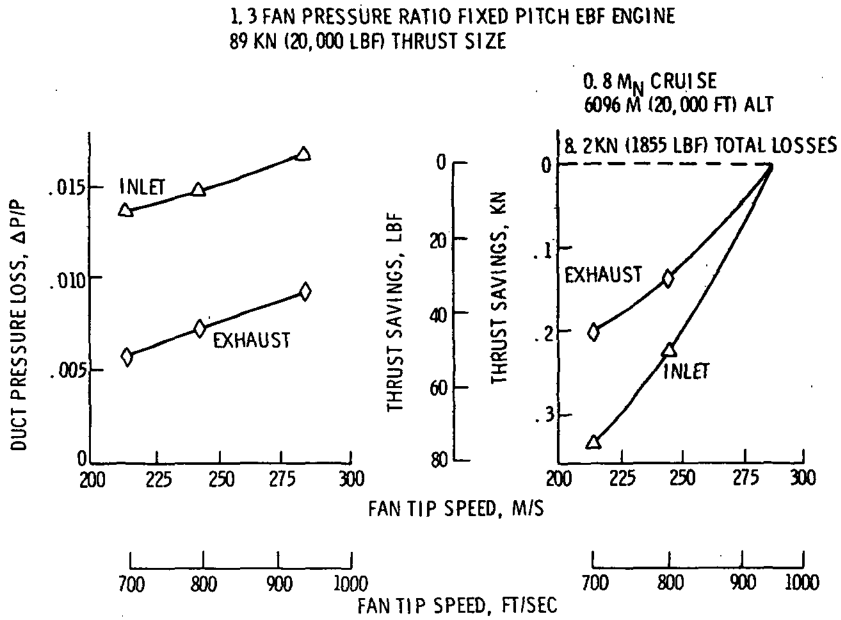


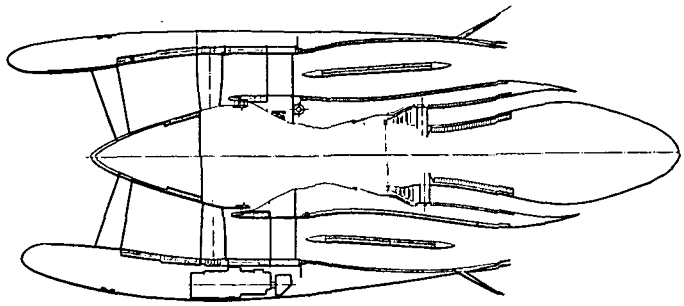
Figure 14. - Powered lift noise, over-the-wing and under-the-wing EBF systems.



(a) DUCT PRESSURE LOSS.

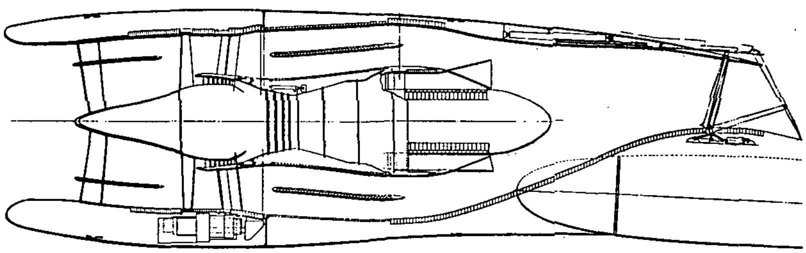
(b) THRUST SAVINGS.

Figure 15. - Reduced fan tip speed effect.



FAN PRESSURE RATIO	1.25
OVERALL PRESSURE RATIO	15.5
BYPASS RATIO	15.0
FAN DIAM, CM	211
TURBINE INLET TEMP, ^{o}K	1622 (2460^{o} F)
THRUST, kN (LB)	107 (24 000 LBS F)

Figure 16. - Blown flap-under-the-wing variable pitch fan engine.



FAN PRESSURE RATIO	1.35
OVERALL PRESSURE RATIO	22.7
BYPASS RATIO	8.3
FAN DIAM, CM	178
TURBINE INLET TEMP, ^{o}K	1590 (2400^{o} F)
THRUST, kN (LB)	107 (24 000 LBS F)

Figure 17. - Blown flap-over-the-wing fixed pitch fan engine.

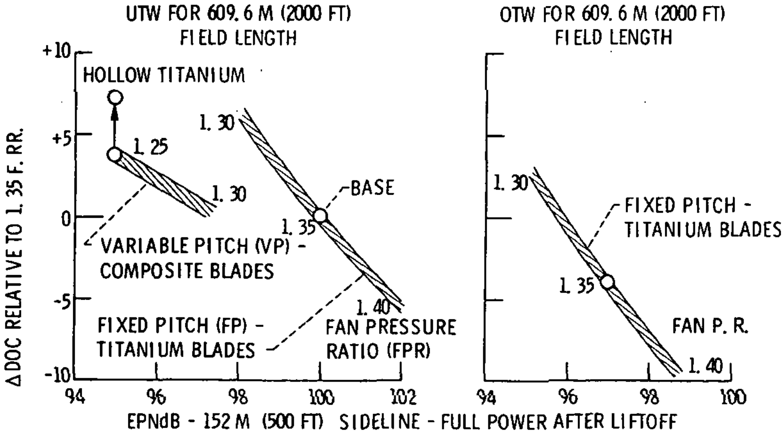


Figure 18. - DOC trades with noise goal for EBF systems.

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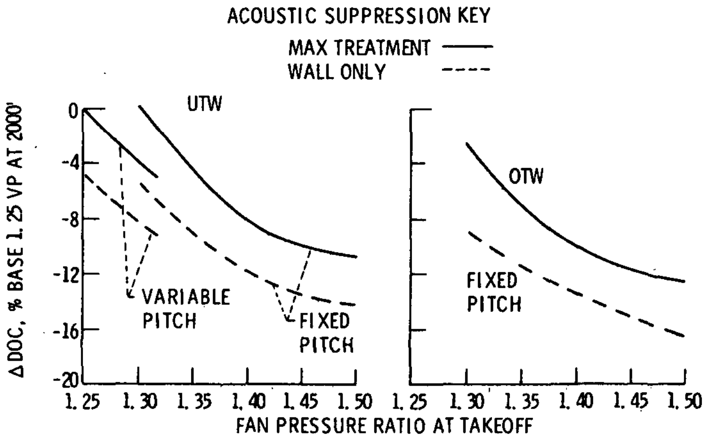

Figure 19. - DOC trades with acoustic suppression.

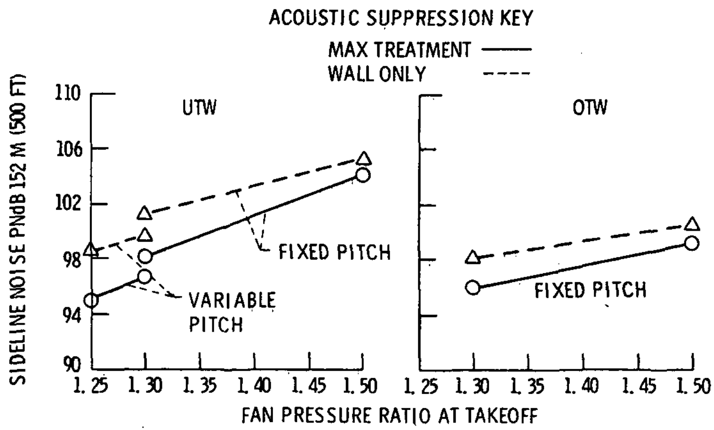

Figure 20. - Sideline noise trades with acoustic suppression.